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FOOTRESTS ON UPWARD EJECTION SEATS

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WRIGHT AIR DEVELOPMENT CENTER

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FOOTRESTS ON UPWARD EJECTION SEATS

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Aero Medical Laboratory

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Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

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FOREWORD

Analysis of human tolerance to forces imposed during escape from aircraft is a responsibility of the Biophysics Branch, Aero Medical Laboratory under RDO No. 695-61, "Escape from High Speed Aircraft."

High speed motion picture coverage and analysis was furnished by Mr. P. M. Moyer and Mr. R. E. Price of the Technical Photographic Service Section.

Instrumentation was installed and operated by Mr. R. B. Chin of the Aero Medical Laboratory. Captain K. F. Hecht, Capt. W. S. Rothwell, Lt. E. G. Sperry and Corporal J. J. Ranta were test subjects. Lt. Sperry served as project engineer.

ABSTRACT

Tests were conducted to determine the importance of footrests on ejection seats, using a 100 foot vertical ejection seat test tower and a mock-up which simulated the control wheel, instrument panel and rudder pedals of the B-47B pilot's position.

The paths followed by the toes and knees during ejection were varied by changing the catapult, size and weight of shoe and position of the leg at the time of ejection.

Three principle test conditions were studied:

a. Footrests removed, feet extended on rudder bar.
b. Footrests removed, feet retracted against seat.
c. Footrests in place, feet extended on rudder bar.

Results were recorded by (a) high speed motion pictures, (b) accelerometers placed on the man's hip and on the seat, and (c) time and distance magnet displacement to measure velocity. The subject was briefly examined before and after each test.

It is recommended that footrests be included on all ejection seats, to support leg weight below the knees and to provide about 3 inches additional knee clearance during ejection.

It is further recommended that sharp leading edges on footrests be avoided in order to eliminate the possibility of leg injury when the feet are not positioned during ejection.

The security classification of the title of this report is UNCLASSIFIED.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDING GENERAL:

Robert H Blount

ROBERT H. BLOUNT
Colonel, USAF (MC)
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INTRODUCTION

Footrests were provided on the earliest ejection seats to insure adequate knee clearance and to enable the pilot to kick away from the seat after ejection. Subsequent designs of ejection seats have always provided foot support of some kind. The evolution of footrests on USAF ejection seats began with the acquisition of German ejection seat data at the end of World War II. (1) The German footrest, which is illustrated in Figure 1a, consisted of a curved pipe suspended below the seat pan which supplied support to the arch. The feet were placed in this stirrup just prior to ejection.

Footrests on ejection seats in F-80 aircraft illustrate the first change from the German design. The basic structure is still tubular; however, support is applied to the heel as well as the arch, this is shown in Figure 1b. This design offered adequate support but it has the disadvantage that the pilot, if subjected to several g's, might not be able to lift his feet and place them in the footrest. It was decided, therefore, that the leading edge should be thin and flush with the floor, thus enabling the pilot to position his feet with minimum effort. The resulting 'ramp type' footrest, which is illustrated in Figure 1c, provides support for the entire foot and seemed to be an improvement.

Interest was again focused on footrests when it was decided that ejection seats should be installed in B-47B aircraft. The co-pilot's seat in a B-47B swivels so that the co-pilot can face either fore or aft, and footrests must be stored in a position under the seat pan where they will not interfere with seat travel. The mechanism for storing the footrests under the seat pan until just prior to ejection weighs 20.75 pounds and is quite complex. The footrests on the pilot's seat, which are not retracted, weigh only 4.93 pounds. In order to eliminate the 20.75 pounds, it was suggested that the rests be removed from the co-pilot's ejection seat. Before a decision could be made it was necessary to examine critically the importance of footrests on ejection seats; therefore, the tests described herein were initiated.

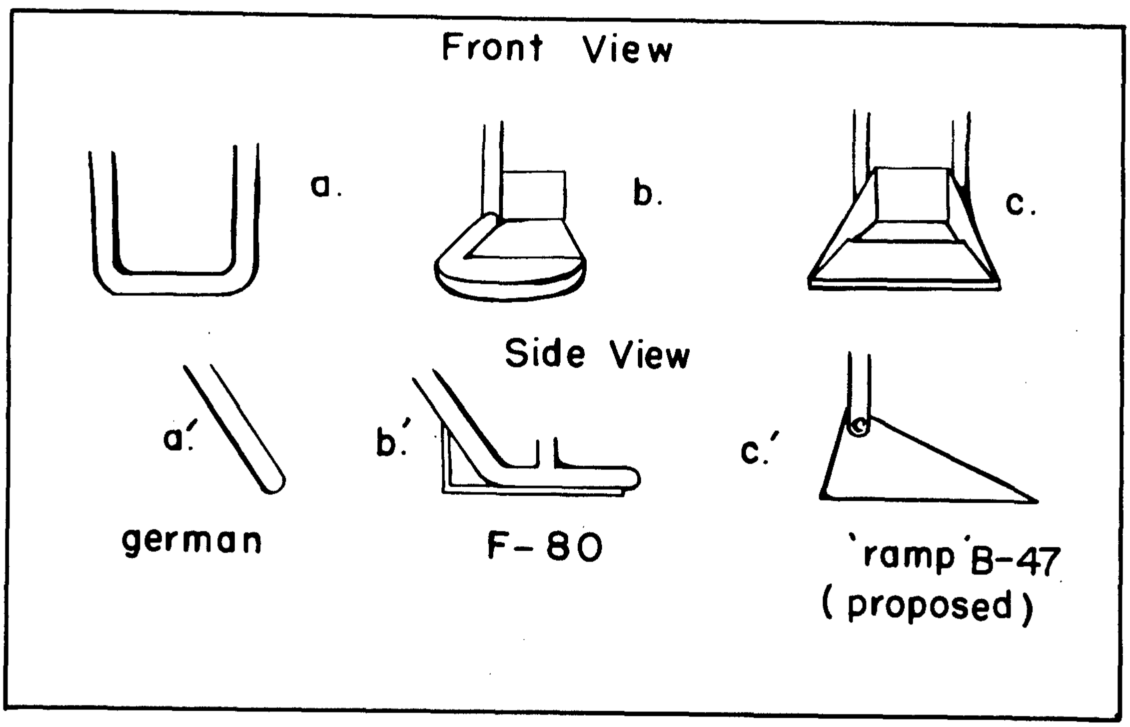

Figure 1.

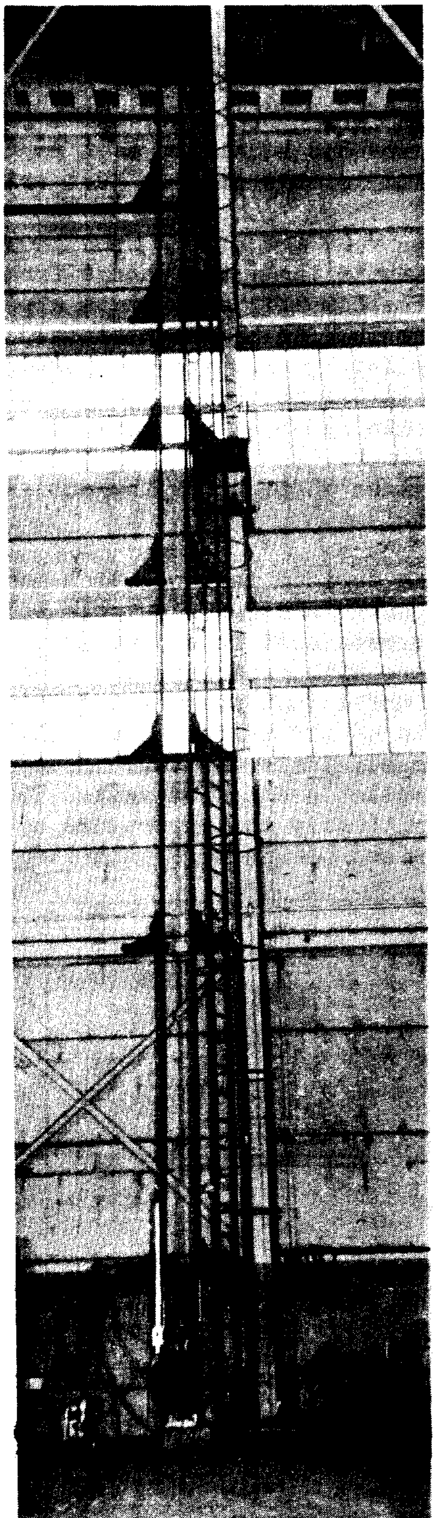

Figure 2.

EXPERIMENTAL METHODS

All tests were conducted on an upward ejection seat test tower consisting of a typical ejection seat mounted so that the occupant rides up a vertical track and is suspended at the highest point in his path by a ratchet brake (Figure 2). Sixteen millimeter motion picture at a frame speed of 2,000 frames per second were taken from the left side of the seat during each test so that high speed motion pictures of the first ten feet of seat travel were obtained for each test. Subsequently, these pictures were analyzed to determine the path of the toe and the knee. Acceleration measured on the hip and on the seat was recorded from unbonded strain gauge accelerometers (Statham, Type F). For purposes of determining the path of the feet, a wooden platform was constructed with a rudder bar and tape was stretched from wood supports to simulate an instrument panel and a stowed control wheel.

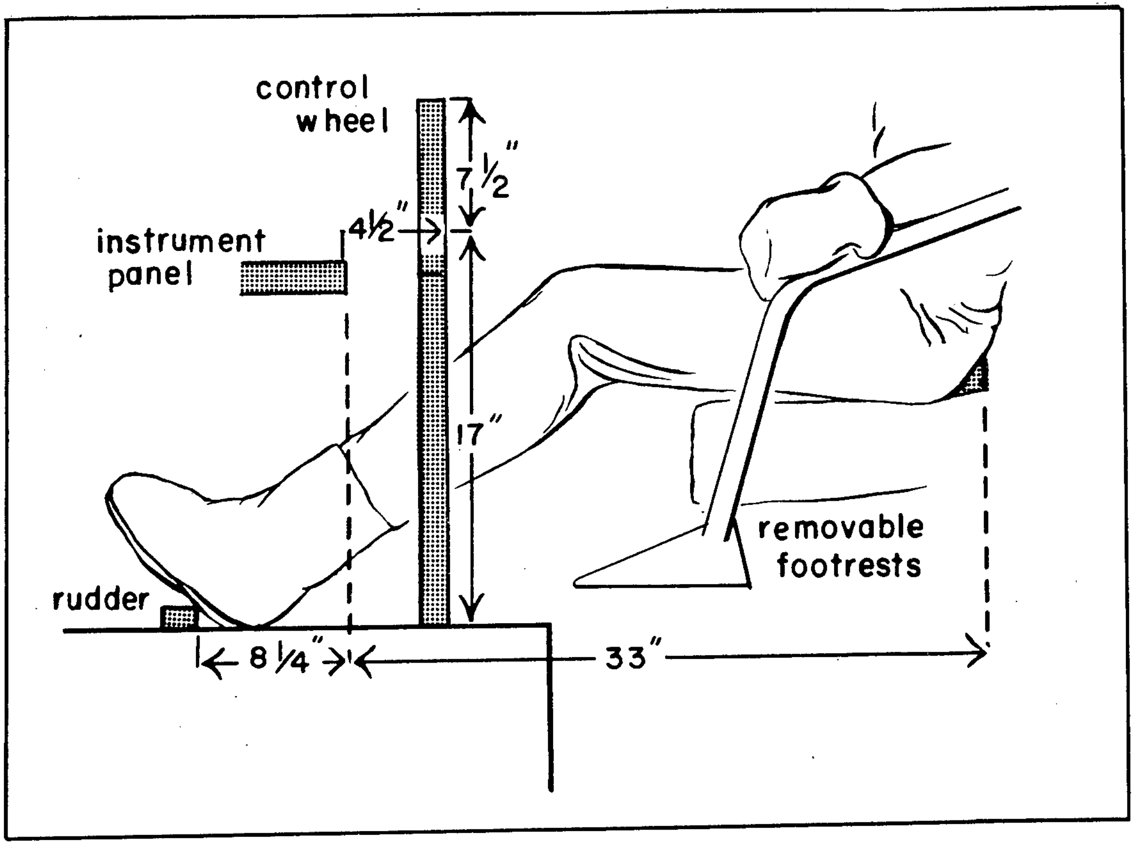

Figure 3.

The model, which is illustrated in Figure 3, simulated the clearances available in the pilot's position of the B-47B aircraft with the rudder pedals fully extended.

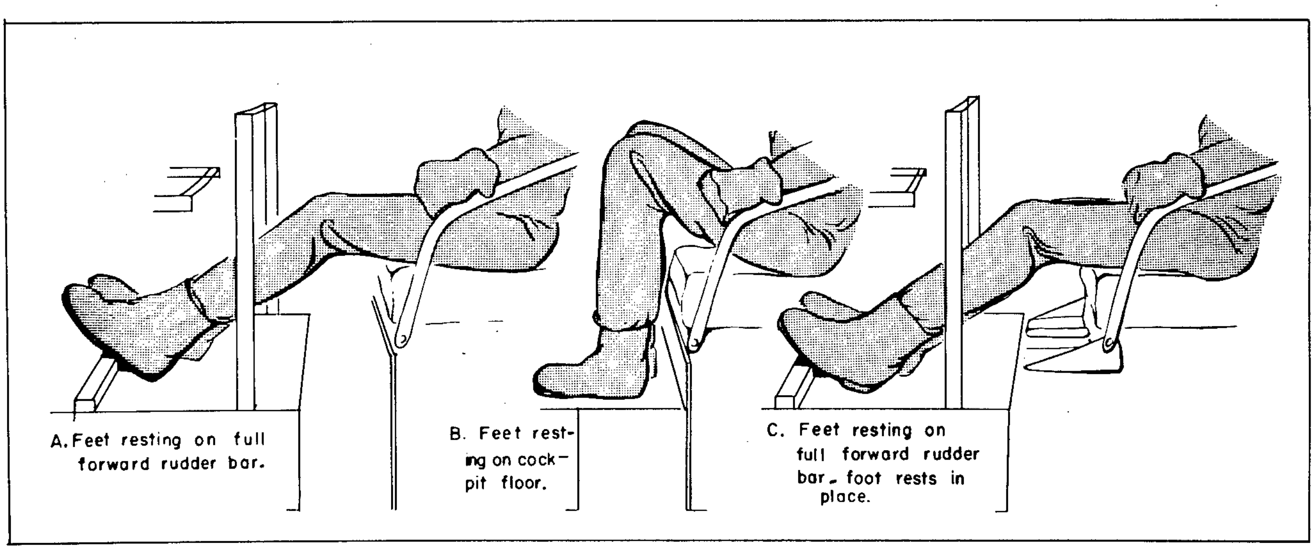

Figure 4.

Ejections were made under three basic conditions:

Condition A. With the footrests removed, the legs extended and the feet placed on the fully extended rudder bar. (Figure 4A)

Condition B. With the footrests removed, the legs hanging vertically and feet resting on the cockpit floor. (Figure 4B)

Condition C. With the footrests in place, the legs extended and the feet placed on the fully extended rudder bar. (Figure 4C)

The writers were subjects in the majority of tests and since they were of average height (5 feet, 10 inches), the platform was moved four inches closer to the seat for their tests in order to simulate the clearances which would exist with a taller man in the B-47B. All tests were made with subject sitting on a dinghy pack with a back pack parachute behind him.

Before and after each test the subject was examined by a physician.

PROCEDURES AND RESULTS

Condition A. The five tests summarized in Figure 5 were made with the footrests removed, the legs extended, and the feet placed on the fully extended rudder bar (Figure 4A).

SUMMARY OF TEST CONDITIONS

	Shoe Type	Catapult	Peak 'g'	Vel. F/sec	Rate of Onset G/sec	Remarks
Condition A						
Test 1	A-6 Boots	M-2	10.6	53.0	107	Calves and back of thighs bruised.
2	Low Quarter	M-2	11.2	52.0	119	Calves and back of thighs bruised.
3	A-6 Boots	M-1	14.9	65.0	141	Calves and back of thighs bruised.
4	A-6 Boots	T-5E2	15.0	68.0	80	Same as above; additional pain around anus.
5	A-6 Boots	M-2	---	---	---	Severe bruising of calves and back of thighs.
Condition B						
Test 1	Low Quarter	M-2	9.9	49.3	106	Back of thighs bruised; oozing of blood.
*2	A-6 Boots	T-5E2	15.0	66.5	81	Moderate pain to thighs and around anus.
Condition C						
Test 1	A-6 Boots	M-1	13.3	59.0	97	Swollen calf; limped for several days.
2	A-6 Boots	M-1	15.6	65.0	137	Swollen calf; limped for several days.

All tests were conducted with dinghy pack and back type parachute.
* Test made after front lip of seat pan was reduced in height.

FIGURE 5

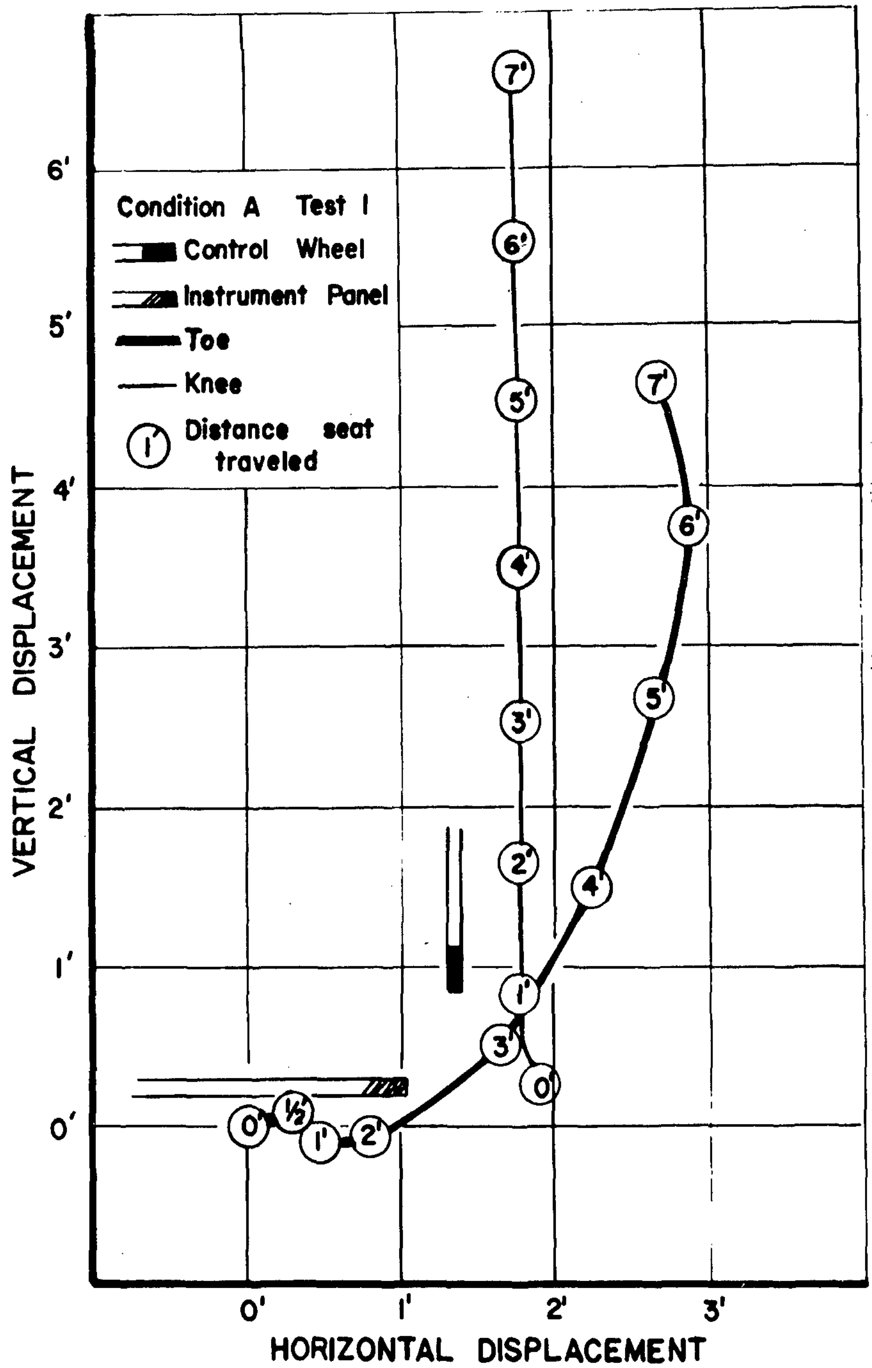

Figure 6.

In Test No. 1 the toes cleared the instrument panel by 2 3/4 inches as is shown in Figure 6, The legs swung back vigorously under the seat and transient redness and tenderness of both calves was noted after the ride despite the fact that the under-edge of the seat was padded with 1 inch of foam rubber. In addition, slight bruising was present on the posterior aspect of the thighs. Presumably, this was caused by contact with the front edge or lip of the seat pan when the dinghy pack was compressed.

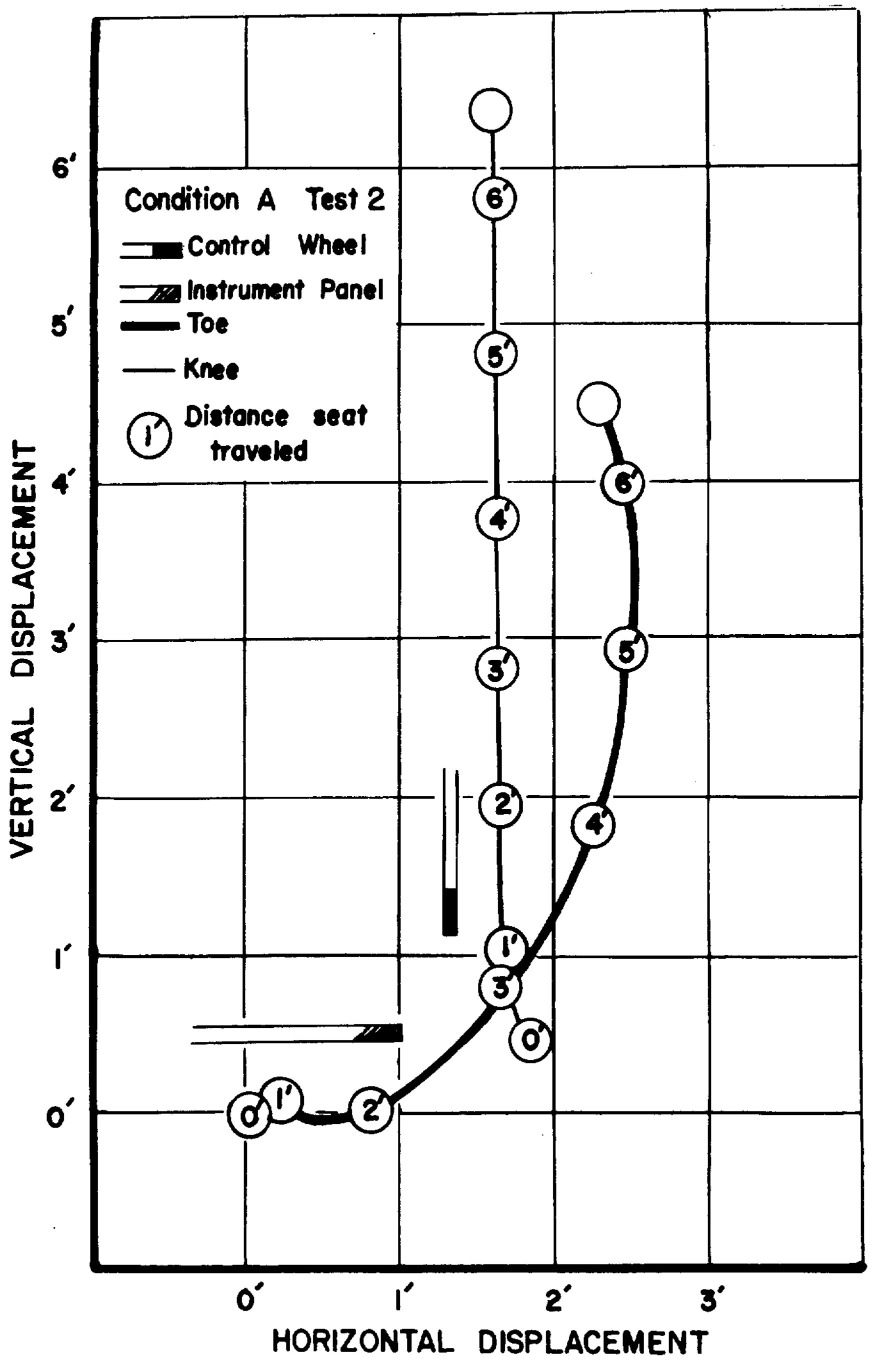

Figure 7.

Test No. 2 was conducted in a manner identical to the first test except that regulation low quarter shoes were worn instead of A-6 boots. The subject noted discomfort in the same locations as on the previous test; however, the degree was less. Because of the shorter length of the shoes (relative to the A-6 boots), the starting point and subsequent path of the toes were displaced downward 3 inches as compared to their position in the first test. Otherwise, the path of motion of the toes and knees was essentially the same. The toes in this instance cleared the instrument panel by 4 1/4 inches as is shown in Figure 7.

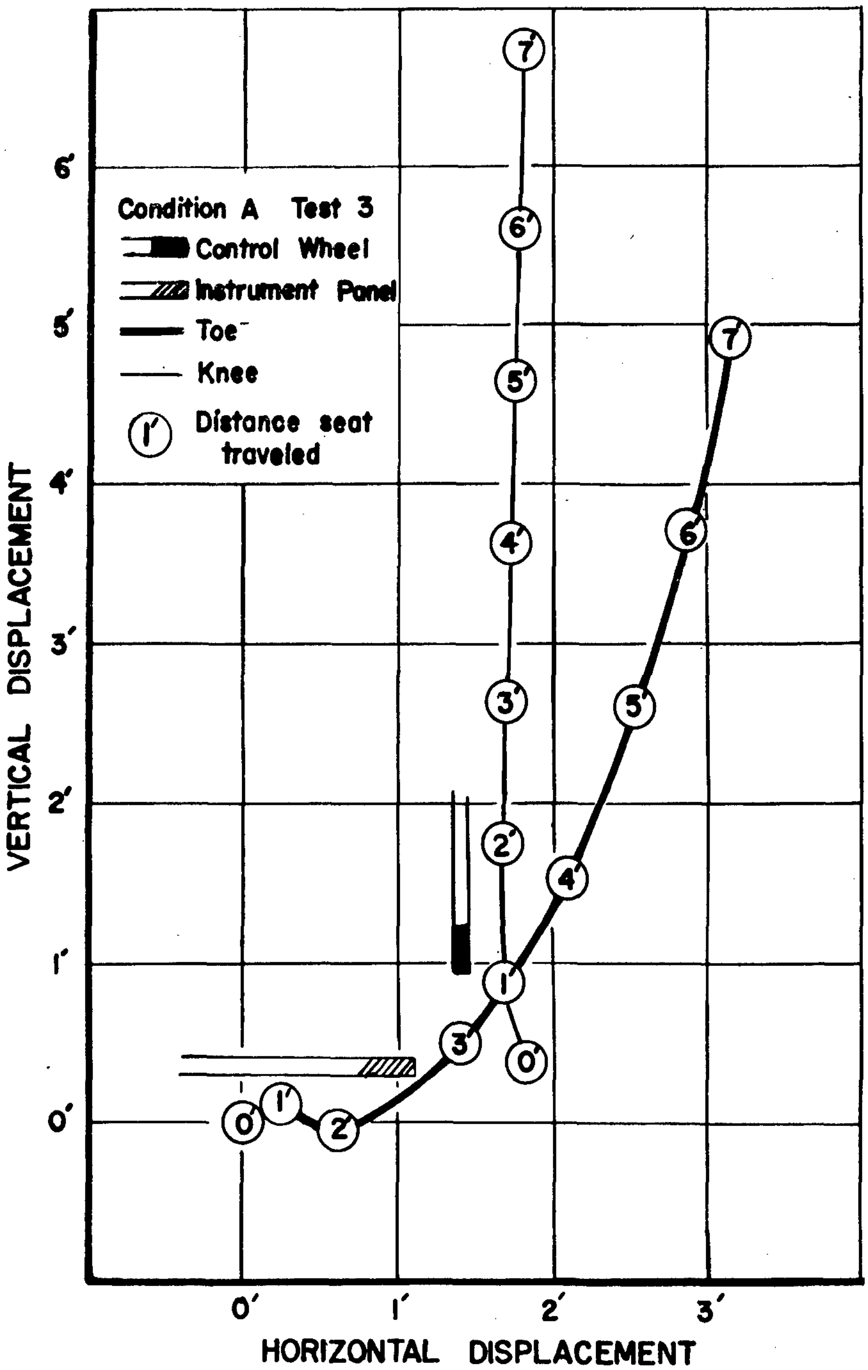

Figure 8.

In Test No. 3 the more powerful M-1 catapult was used and the subject wore A-6 boots, which were more likely to strike the instrument panel than the low-quarter shoes. He again noted discomfort in his calves and the back of his thighs; however, the severity was not much greater than with the indoctrination catapult previously used. The discomfort was of short duration and in no way interfered with his ability to walk. The toes cleared the instrument panel by 2 inches as is shown in Figure 8.

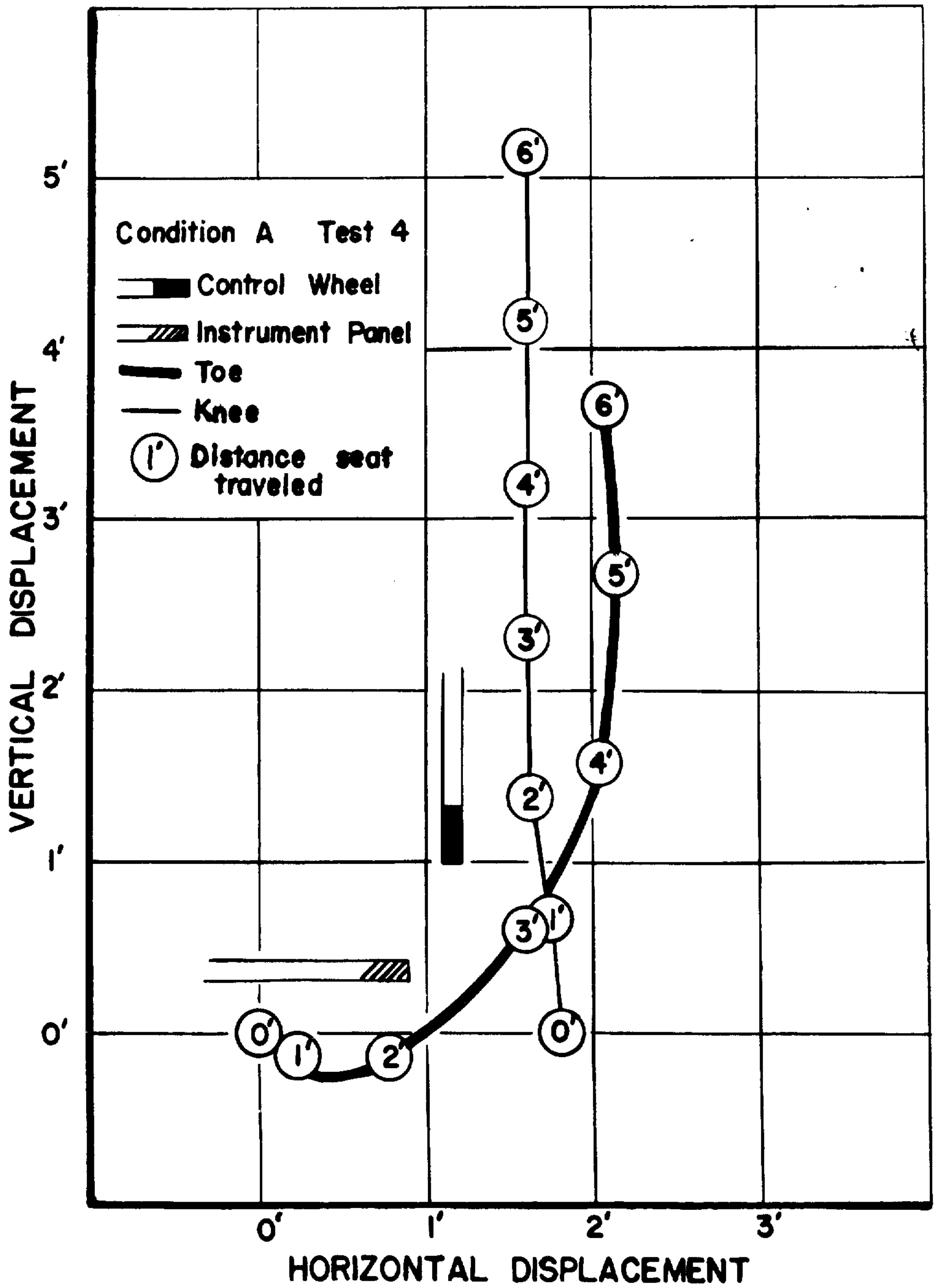

Figure 9.

In Test No. 4 the subject again wore A-6 boots and the most powerful catapult available (T5E2) was used. He noted discomfort in the thighs and calves as before but it was no more severe than that felt with the previous catapults. The subject experienced moderately severe pain around the anus for approximately one minute after the ride*. The significance of this pain has not been determined. It may have represented a prolapse of rectal mucosa which spontaneously reduced itself. Figure 9 shows that the toes cleared the instrument panel by five inches.

* This pain was not noticed during later tests of the T5E2 catapult (the most powerful catapult available) when the subject was in a normal ejection position.

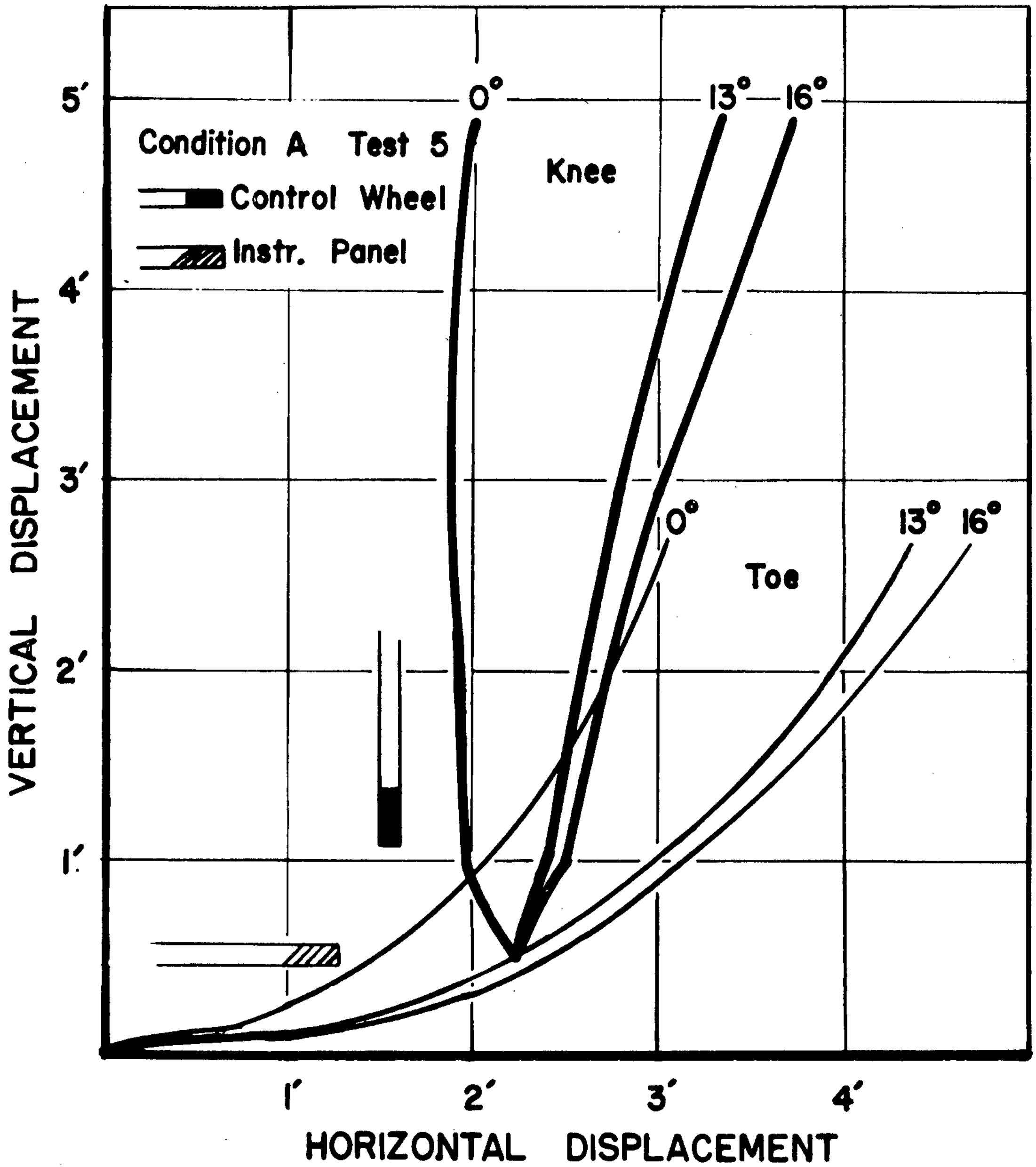

Figure 10.

The subject in Test No. 5 was 6 feet 4 inches tall and wore large size A-6 boots. Anthropometric data indicated that only 4 men in 2,000 would be expected to have a longer leg length. The platform incorporating the simulated instrument panel and stowed control column was placed in a position where clearances were the same as actually present in the B-47B with rudder pedals in full forward adjustment. This test was made primarily to check the hypothesis that the clearances for a man of average height with the mockup platform moved four inches closer to the seat (as was the case in all other tests) would approximate the clearance available for a taller man with the mockup in normal position. The toes in this instance cleared the instrument panel by 2 1/4 inches. This clearance is similar to that obtained on shorter subjects (5 ft. 10 in.) with the mockup platform moved 4 inches nearer to the seat. The path of the legs and knees was similar to those previously obtained.

A muscular cramp, like a "charley horse", was noted behind the knee for about three minutes after the ride. The subject also sustained sharply defined linear bruises on the posterior aspect of both thighs and some soreness in both calves and thighs for about five days following the ride. The location of the bruises on the thighs suggests that they were caused by contact with the rolled edge of the dinghy pack. When this subject was in position for ejection, it was noted that his thighs were elevated approximately five inches from the surface of the dinghy pack; whereas in all previous tests with feet on the rudder bar, the thighs rested on the dinghy pack.

Discussion of Tests Under Condition A. The curve described by the toes, during simulated ejection on the upward ejection seat test tower with legs extended, in all cases resembled a catenary. Even though a different catapult was used on the same subject in three successive tests, the path of the toes was essentially the same. This is demonstrated by the following tables taken from Condition A.

REARWARD MOVEMENT OF TOE (In Feet)

	Seat Travel in Feet					
Catapult	1 ft.	2 ft.	3 ft.	4 ft.	5 ft.	6 ft.
M-2	.3	.8	1.6	2.2	2.6	2.9
M-1	.2	.6	1.4	2.1	2.5	2.8
T-5	.2	.7	1.6	2.1	2.15	2.1

UPWARD MOVEMENT OF TOE (In Feet)

	Seat Travel in Feet					
Catapult	1 ft.	2 ft.	3 ft.	4 ft.	5 ft.	6 ft.
M-2	.1	-.1	.5	1.5	2.7	3.8
M-1	.1	-.05	.5	1.5	2.6	3.7
T-5	-.1	-.2	.6	1.6	2.7	3.7

This close similarity of foot travel path would seem to indicate that the difference in performance between the three catapults in this instance is not of great magnitude. Figure 5 compares the performance characteristics of the various catapults which were used.

The ejection seat test tower used in these experiments is perpendicular to the floor, whereas ejection seats in aircraft slant aft from 13° to 16°. The toe and knee paths recorded on the test tower must be corrected to allow for this slant. In Figure 10, the paths of toe and knee of the 6 foot 4 inch subject are adjusted to allow for slant in ejection rails. If the resulting curve is placed on an inboard profile view of an aircraft, the paths of the toes and knees in relation to the aircraft structure can be determined.

Increased Knee Clearance

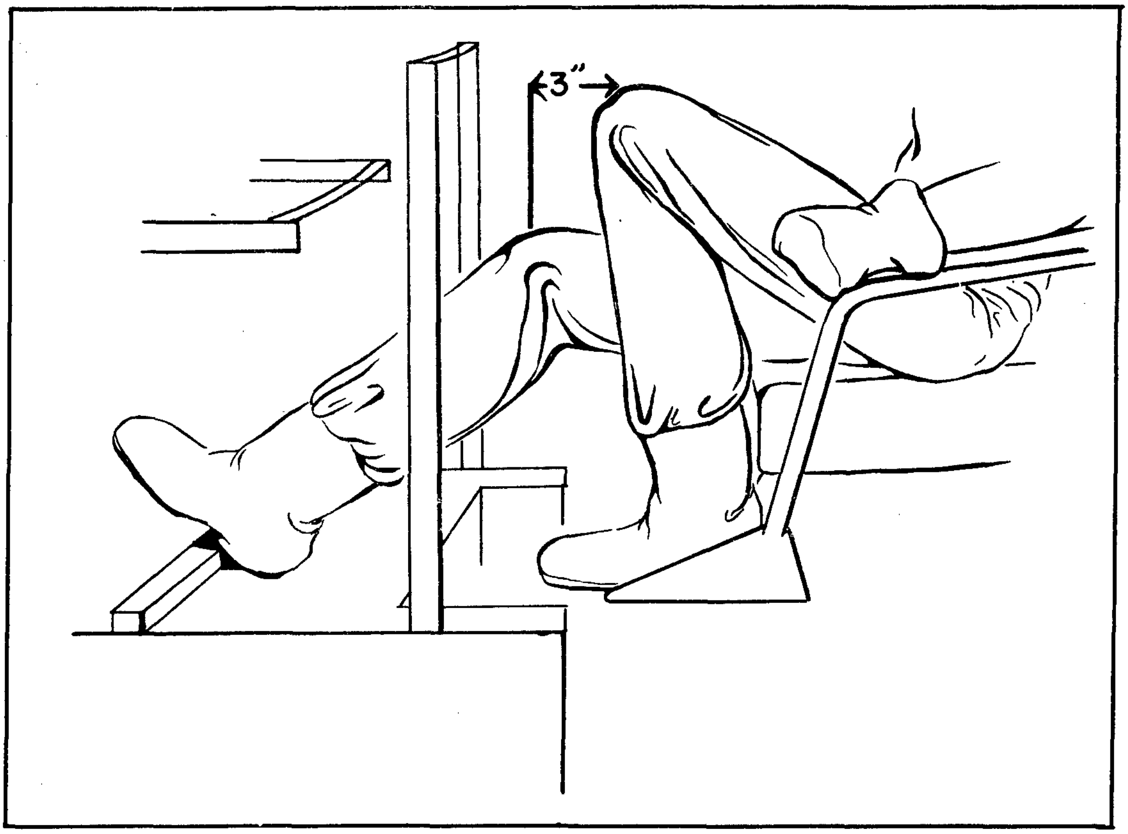

Figure 11.

During this test series it was noted that the knees are displaced forward 3 inches when no footrests are provided because the thighs assume a horizontal position instead of maintaining their upward angulation. The increased knee clearance is illustrated in Figure 11.

Conclusions Condition A. These tests demonstrated that sufficient clearance exists in the copilot's station of the B-47B so that a copilot taller than 5 feet 10 inches can eject himself with his feet on the fully-extended rudder pedals without striking any structure. The tests also indicate that there is sufficient clearance for a man 6 feet 4 inches tall under the same conditions. However, failure to use footrest will reduce the clearance of the knees by approximately 3 inches.

No serious injury resulted from these simulated ejections (i.e., no injury severe enough to hamper a man in taking evasive action), although there was bruising which is not encountered in ejection when the feet are on footrests. The first three tests indicated a need for a vertical backstop for the legs since the legs swing vigorously backward under the seat. Such a backstop was used on the two succeeding tests. It was also believed that a backstop would be needed in flight to prevent windblast from forcing the legs back under the seat and spraining or otherwise injuring the knee. Such a backstop, however, might unfavorably influence the seat trajectory.

Condition B. With the footrests removed, the legs hanging vertically and feet resting on the cockpit floor (Figure 4B). In both tests of this condition the distance from the seat pan lip to the level of the cockpit floor was such that the thighs were elevated above the surface of the seat. This distance between the forward edge of the dinghy pack and posterior aspect of the subject's thighs is subsequently referred to as "elevation of the thighs." These tests are summarized in Figure 5.

In Test No. 1, elevation of the thighs was 8 inches. The rider noted some pain in the back of his thighs and there was linear bruising and abrasion of the back of the thighs with slight oozing of blood. It is presumed that the 5 inch dinghy pack compressed sufficiently during ejection to allow contact between the thighs and the $3\frac{1}{2}$ inch high rim of the seat pan. The subject was able to walk without difficulty following the test, although the bruises remained for several days.

In Test No. 2, because of the bruising which occurred on the previous test and the possibility that more serious injury might result with the larger catapult, only the left footrest was removed with the left foot resting at the level of the cockpit floor. The right foot was placed in the right footrest. In addition, the forward edge of the seat pan was reduced in height from $3\frac{1}{2}$ inches to $1\frac{1}{2}$ inches. Elevation of the left thigh was 7 inches. An accelerometer was mounted on the left thigh at a point on the anterior surface opposite the point where contact was made with the edge of the dinghy pack on the back of the thigh. Analysis of this record revealed an acceleration of 23.4 'g' when the thigh struck the dinghy pack. The rider noted some pain in the back of the thigh, but no bruises were evident and the subject's ability to walk was not impaired. He also noted stinging perirectal pain of one to two minutes duration which was the same as that previously mentioned as occuring during tests with the same catapult by another subject.

Conclusions Condition B. With the legs vertical and the feet resting on the cockpit floor, no clearance problem exists at the copilot's station in the B-47B. No injury sufficient to hamper a man's ability to walk was sustained in these tests. However, in the event that the footrests were removed, it would be desirable to lower the height of the front edge of the seat pan to eliminate the possibility of injury to the thighs. Contoured metal tops, such as are used at present on the seat survival kits, might also be undesirable under such circumstances.

Condition C. With the footrests in place, the legs extended, and the feet placed on the fully extended rudder bar (Figure 4C).

Test No. 1. It was deemed advisable to determine whether clearance was still adequate at the copilot's station if the footrests were left in place but the subject's feet were on the rudder bar at the moment of firing. Because of the possibility of injury only the left foot was placed on the rudder bar in both tests of this condition, the right foot being placed in its foot rest. The leading edge of the footrest was formed by a straight piece of pipe one inch in diameter and padded with foam rubber. The subject's feet and knees cleared all structures. However photographic coverage of this test was not obtained due to malfunction of the catapult trigger which delayed the ejection until the camera was empty. The subject noted considerable pain in the left calf when the leg swung back against the footrest. He was unable to walk without an obvious limp for three days and, although there were no superficial bruises, the left calf was definitely swollen.

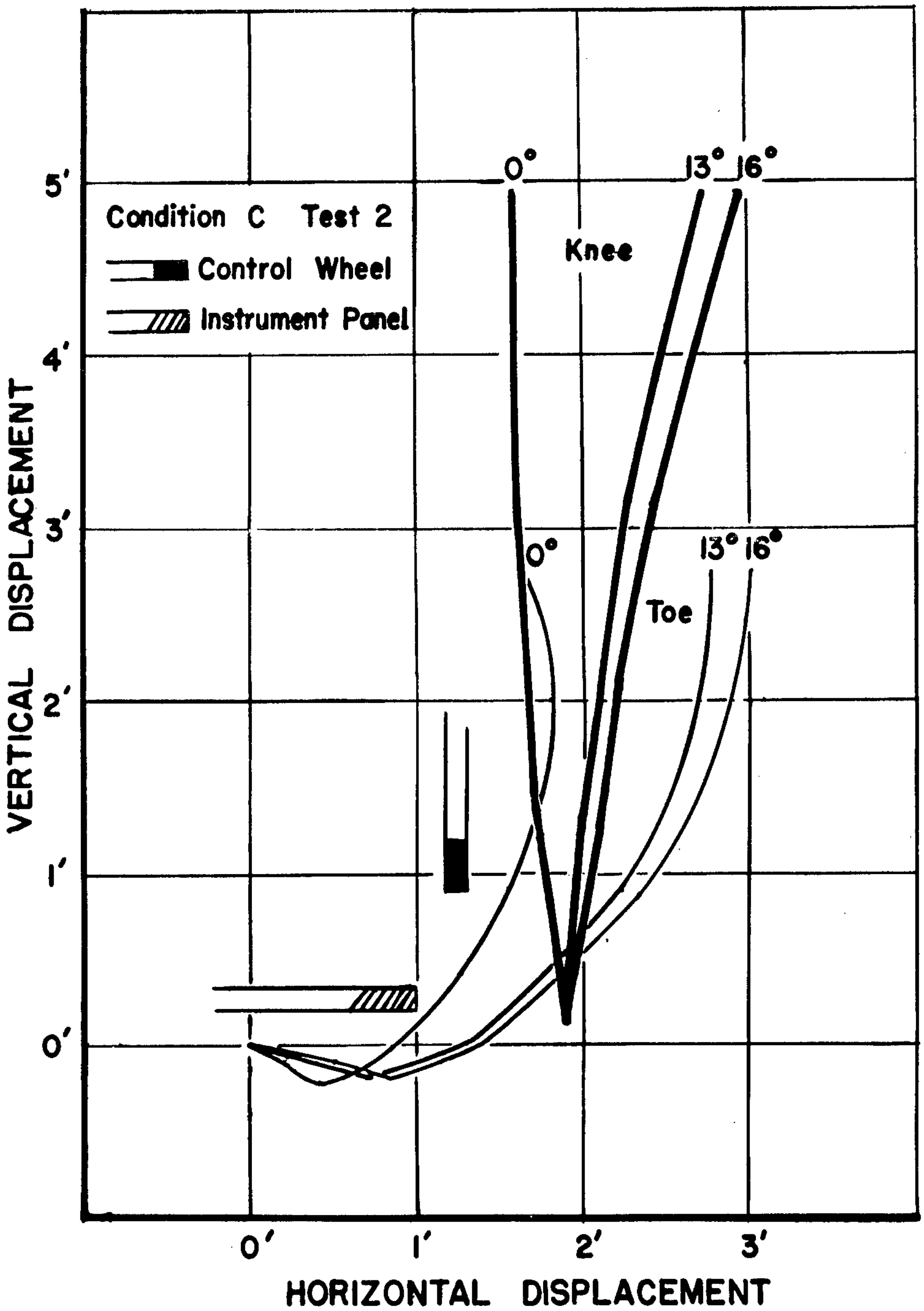

Figure 12.

<u>Test No. 2.</u> This test was essentially a repeat of the first test in order to obtain photographic coverage. The toes cleared the instrument panel by 7/8 inches. The subject also noted considerable pain in the left calf and walked with a marked limp for 4 days. There was evident swelling of the left calf without any superficial bruising. The toe and knee paths which are shown in Figure 12 have been corrected to allow for a slant in ejection rails which would exist in an aircraft installation.

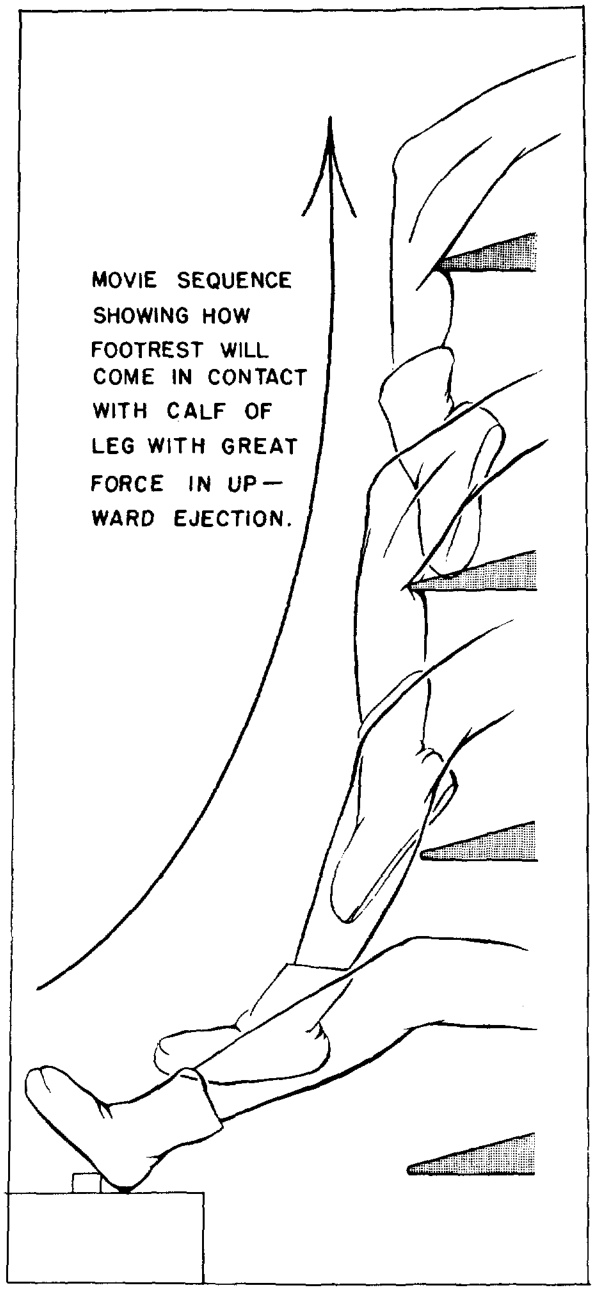

Figure 13.

<u>Conclusions Condition C</u>. There is sufficient clearance at the copilot's station for a man to eject with both feet on the rudder pedals when footrests are in place. However, it is likely under such circumstances that his legs would be injured by the leading edge of the footrests to such an extent that it would be difficult or impossible for him to take any necessary evasive action. The action of the leg striking the footrest is illustrated in Figure 13. The present tendency in footrest design is to convert the forward part of the footrest to a ramp with a relatively sharp leading edge so that the foot can readily slide back into the footrest. This may be a satisfactory arrangement if the ramp portion has a spring-loaded hinge so as to present a flat vertical bearing surface to the leg in the event that the foot is not in the footrest at the time of ejection. If the ramp portion, with its relatively sharp edge, is rigid, serious injury may result with some frequency, since records of ejection bailouts indicate that 20 per cent of personnel using the ejection seat fail to get their feet in the footrests at the time of ejection (2). A simple remedy would be to use a rather thick bar or pipe on which the pilot could position his arch, as the leading edge of the footrest. Such a footrest would be as simple to get the feet into as the ramp type, provided the cockpit floor were recessed so that the upper surface of the footrest were flush with the floor.

SUMMARY

The toes and knees will clear cockpit structures during ejection from either the copilot's or the pilot's position in a B-47B, whether footrests are provided or not. When footrests are used, the knees are in a position approximately 3 inches further aft than when no footrests are present. Since many aircraft, such as the F-94C, have a smaller ejection envelope than is provided with the B-47B, three additional inches of clearance may be essential and it is believed that the presence of footrests on some aircraft and their absence on others would tend to confuse the ejection seat sequence which is already considered too complex. During ejection without footrests, the calves and thighs will be painfully bruised and, since the feet will be dangling below the seat pan as the man and seat enter the slipstream, the knees may be wrenched. Even prior to the seat's entering the slipstream, it is possible for the knees to be wrenched by being flung back under the seat pan. In view of the above factors, footrests are deemed essential and should be provided on all ejection seats.

Sharp leading edges are a great hazard. A flat or round leading edge is necessary to present ample surface to the leg during ejection when footrests are not used. The rests should be recessed into the aircraft floor so that the pilot can easily position his feet when subjected to 'g's.

Support of the foot at the arch, as in the case of the German footrests is considered adequate.

REFERENCES

1. Memorandum Report; TSEAL-3-696-74C "The Ejection Seat for Emergency Escape from High-Speed Aircraft", 31 August 1945.

2. "Analysis of Ejection Seat Operation in Jet Fighter Accidents" Directorate of Flight Safety Research, May 1951.